PRF Ambiguity Determination
for Radarsat ScanSAR System

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Abstract

PRF ambiguity is a potential problem for a spaceborne SAR operated at high frequencies. For a strip mode SAR, there were several approaches to solve this problem. This paper, however, addresses PRF ambiguity determination algorithms suitable for a burst mode SAR system such as the Radarsat ScanSAR. The candidate algorithms include the wavelength diversity algorithm, range look cross correlation algorithm, and multi-PRF algorithm. This paper gives detailed description for the later two algorithms and suggests a reliable data processing step to accomplish all three processes,

Keywords: Doppler centroid, PRF ambiguity, ScanSAR, SAR burst, wavelength diversity, range offset , multiple PRF.

INTRODUCTION

In SAR processing, knowledge of the radar pointing direction is required for estimating the Doppler centroid [1] of the echo data. The Doppler centroid estimate is used in selecting the processing frequency window, in azimuth reference generation, and in determining the range walk path of the azimuth spectrum. Accurate Doppler centroid estimate is necessary for meeting the signal-to-noise (SNR) ratio and signal-to-ambiguity (STA) ratio specified in the system design, in case the accuracy of the pointing knowledge is not accurate enough, one can get more accurate Doppler centroid estimate based on the SAR echo data, When the Doppler centroid error is confined with the range of $(-PRF/2, PRF/2)$, Doppler centroid estimation can be made based on the algorithms reported in [1,2,3].

For high frequency band SAR, such as C and X band, the uncertainty of the pointing knowledge can easily lead to a Doppler centroid error exceeding one half of the pulse repetition frequency (PRF) value. in such cases, the Doppler centroid estimation process requires to determine its PRF ambiguity number. Fail to determine the correct PRF number would lead to a degradation in the range resolution of the final SAR imagery [4]. Previously reported algorithms for PRF ambiguity determination include look range cross-correlation algorithm [5,6], multiple PRF algorithm [4], and wavelength diversity algorithm [7]. The look range cross-correlation algorithm requires image contrast in the processed data. The multiple PRF algorithm requires multiple SAR data taken at selected PRF values. The wavelength diversity algorithm is particularly useful for SAR data with very low image contrast.

Except for the wavelength diversity algorithm, all existing PRF ambiguity determination algorithms arc formulated for the strip mode SAR systems only. These algorithms will not be applicale to the upcoming Radarsat mission which will be operated in a ScanSAR mode [8]. Because in this system, the SAR echo is acquired in bursts instead of a long contiguous echo pulses as in the strip mode. The objective of this paper is to devise PRF ambiguity algorithms applicable to the burst mode SAR system.

RADARSAT SCANSAR DESIGN

The Radarsat ScanSAR is capable of mapping a 500 km swath. It is accomplished by a number of overlapped range beams, each is designed for a particular incidence angle. The SAR is operated by alternatively transmitting the radar bursts according to a selected beam sequence. The number of pulses in a burst is roughly *given* by the number of pulses in the full synthetic aperture divided by the product of the number of range beams and the number of azimuth looks. The ScanSAR geometry is depicted in Figure 1.
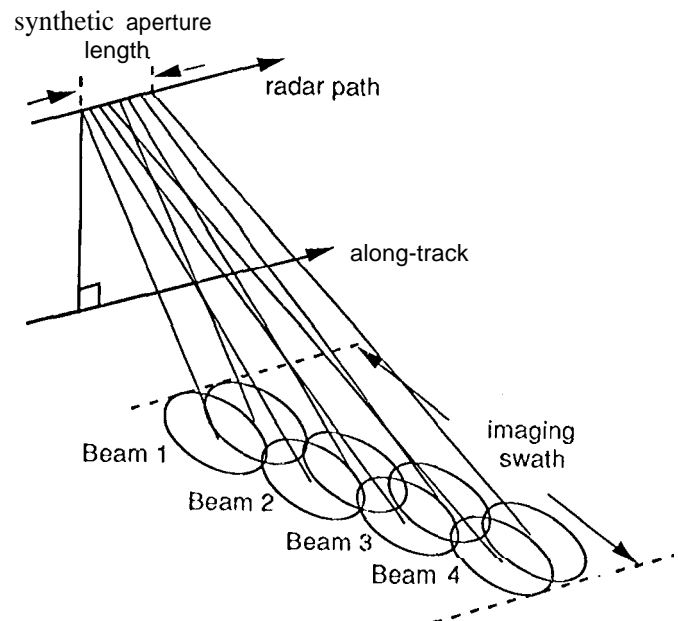

Figure 1. Radasat ScanSAR Beams and Swath

PRF AMBIGUITY DITERMINATION

The basic concept of PRF ambiguity determination algorithm for a ScanSAR is similar to a continuous mode SAR

system. But, these algorithms require some modification, The wavelength diversity algorithm for a ScanSAR is exactly the same as that for a continuous mode SAR. However, since the burst size is constrained by the ScanSAR design, the accuracy of the PRF number estimated from a single burst may not be sufficient. One must improve the accuracy of the PRF number estimate by properly integrating results made from a large number of bursts of the same beam.

In a continuous mode system, the multiple PRF algorithm requires to collect SAR data at several different PRFs. For a ScanSAR system the overlapped area between adjacent range beams are obtained most likely from two different PRFs. Therefore, no extra data taken are required. In continuous mode, the PRF number is determined based upon the delta of each pair of the Doppler centroid estimates, For a ScanSAR, the PRF number is determined based on the along track offset between the two images at the overlapped area.

The look range cross correlation for the continuous mode [4,5] is made in the slant range coordinate. It can also be made in the ground range. For a ScanSAR processor, it is more desirable to use the ground range in a projection coordinate since image registration in the slant range may suffer a degradation due to the range curvature effect,

MULTIPLE PRF ALGORITHM

There arc three ScanSAR designs in Radarsat, two beam, three beam, and four beam ScanSARs. At the overlapped are between two range beams, it is mapped by two distinctive PRF values. The image at the overlapped area may lead to the solution of PRF ambiguity number.

The two images processed from two bursts acquired from two distinctive PRF values are different in the along-track size determined by its own PRF value. The actual image may be smaller than this due to truncation following a specified processing bandwidth. This difference in along-track size is the key for PRF ambiguity determination. This is illustrated in Figure 2, On the top row arc a number of the same images repeated in along-track, each obtained from SAR processing associated with the true Doppler centroid f_d plus $n \cdot PRF_1$ as indicated. On the bottom row arc images, each obtained from SAR processing associated the true Doppler centroid f_d plus $n PRF_2$ as indicated. It is obvious that for the correct PRF ambiguity number the top image and the bottom image can be registered well. However, an along-track offset exist for the other cases.

The Doppler centroid can be formulated as a function of sensor velocity, v, wavelength, λ, and the squint angle θ_s between the sensor velocity and the relative position.

$$f_d = \frac{2v\cos\theta_s}{\lambda}$$

Base on the derivative of Doppler with respect to the squint angle, the error in the along-track position due to Doppler error is given by

$$\Delta x_a = \frac{\lambda\, r}{2v\sin\theta_s} \Delta f_d$$

where r is the slant range from radar to the boresight intercept point on the ground. Hence, the along-track offset between two images at the overlapped area is given by

$$\Delta x = \frac{\lambda\, r}{2v\sin\theta_s} \cdot n \cdot (PRF_2 - PRF_1)$$

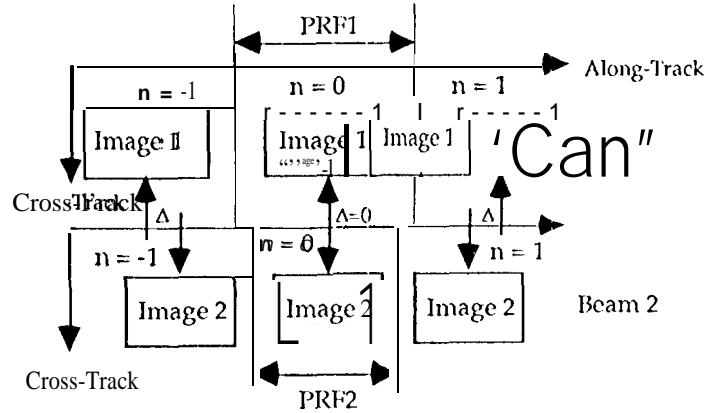The above equation directly leads to the solution of the PRF ambiguity number n.

Figure 2. The Misregistration (A) due to PRF Ambiguity in Two Burst Frames of Different PRFs.

LOOK RANGE CROSS-CORRELATION ALGORITHM

For a strip mode SAR, PRF ambiguity results in range offset between images of two distinct azimuth looks. The amount of offset can be formulated based on the range migration equation. For a burst mode SAR, PRF ambiguity results in range offset between images of two adjacent bursts. This fact can be illustrated as the following. A common ground point illuminated by the radar in both bursts is associated with a unique pair of range and Doppler values with respect to the sensor position and velocity at the center time of each burst. Changing the Doppler value by $n \cdot PRF$ causes the position to move in the along-track dimension as described in the previous section. However, since the range value stays fixed, the target position actually moves along a circle around the nadir point of the sensor at the burst center time. Because the two range circles around the two nadirs have only two intersections (one is the common point without any Doppler error, one is on the other side of the nadir path), the two target positions must be different. There must be an offset between these two positions in the cross-track dimension as illustrated in Figure 3.

To derive the cross-track offset, we assume that the ground surface is a flat plane, the angle between two range circles, according to Figure 4, is given by

$$\phi = \phi_1 + \phi_2 \cong \frac{v_e \cdot T_p}{r\sin\theta_L},$$
$$\text{where } v_e = \text{v.} \ (r_e / (r_e + h))$$

where v_e is the effective spacecraft speed on the ground, T_p is the SAR burst period, θ_L is the radar look angle, and Ay is the cross-track offset between the two frames. _____ the track offset is approximately
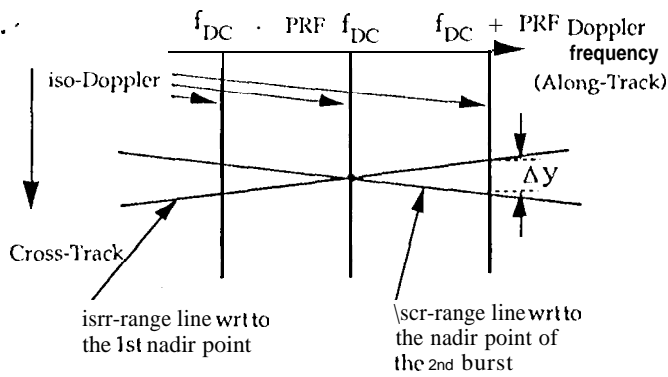
Figure 3. Cross-Track Shift between Two Frames

$$Ay = n \cdot PRF \cdot (\frac{r\lambda}{2v\sin\theta_s}) \cdot \phi$$

$$= n \cdot PRF \cdot \frac{r\lambda}{2v\sin\theta_s} \cdot \frac{v_e \cdot (r_e/(r_e + h)) \cdot T_p}{r\sin\theta_L}$$
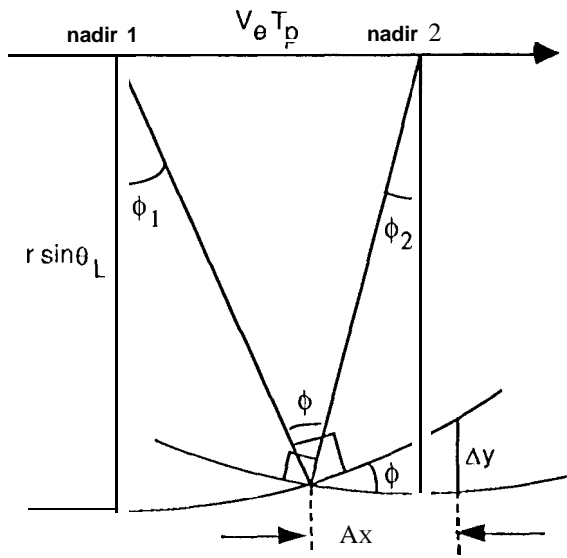

Figure 4. Cross-track offset between two burst images

The first step of this algorithm is to process both bursts into geometrically rectified image frames, which are with full range resolution. A cross-correlation in the cross-track dimension is then made for the intensities of these two image frames, The offset of the two image frames are determined based on the peak response position. The PRF ambiguity number can then be determined as

$$n = Ay \cdot \frac{1}{PRF} \cdot \frac{2v\sin\theta_s}{r\lambda} \cdot \frac{rsin\theta_L}{v_e \cdot (r_e/(r_e + h))} \cdot T_p$$

INTEGRATED PRF AMBIGUITY DETERMINATION

A reliable Doppler centroid estimation algorithm must involve ancillary data processing, a clutterlock process, and all three types of the PRF ambiguity determination algorithms. The first order Doppler centroid estimate obtained from the ancillary allows SAR data processed using the best knowledge

to get images for further processing. The clutterlock process leads to the best estimate of the base Doppler centroid, f_{d-base}, which is defined as

$$f_d = f_{d-base} + n\,PRF$$

where $-PRF/2 \le f_{d-base} \le [' /<?</ 2$ and f_d is the Doppler centroid. Image contrast estimation is also necessary to determine which PRF ambiguity number to choose from. The detailed process flow diagram is given in Figure 5.
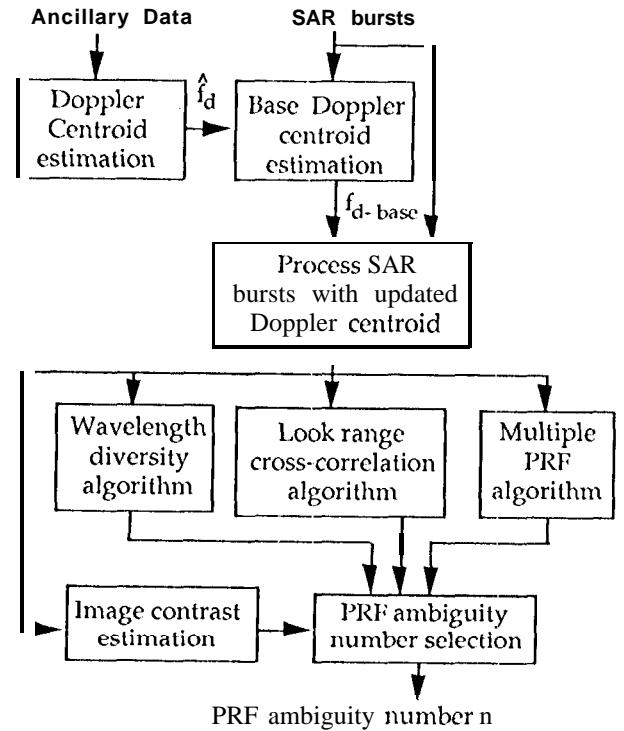

Figure 5. PRF Ambiguity Determination Process Diagram

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